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Analysis and Retrofitting Techniques for a Multi-Storey Building under Construction

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Abstract: The project under consideration consists of a S+G+4 building where the walls for the stilt floor, ground floor and the upper four floors are proposed to be of Aerocon AAC (autoclaved, aerated concrete) blocks (size 800mmx600mmx200mm) which are light-weight (dry density of 550-700 kg/m^3), which is about one-third that of the clay bricks) as well as eco-friendly and have the advantages of faster construction. Now, an addition of two more floors to this building is to be done and the use of the Porotherm clay blocks (dry density 1800 kg/m^3) is proposed for the added floors for better aesthetics and thermal insulation. Due to this increase in the weight, checking for safety of the structure is required. Reinforced concrete (RC) columns and beams in buildings often need strengthening in cases of defects in the member, or in situations of having to support higher loads than those foreseen in the initial design of the structure, accidental damage, etc. They basically need strengthening to increase their capacity to sustain the applied load. For this purpose, suitable retrofitting methods can be applied for the required columns and footing in this project.
Keywords: Analysis, Design, Multi-storeyed, Axial force, Bending moment, STAAD Pro, Retrofitting.

I. INTRODUCTION

The high rise buildings or the 'sky scrapers' are constructed not only for the economy of space but eventually, they are considered icons for a city's identity and economic power. To facilitate the demand of high rise structures, various types of structural systems have been used. The analysis and design for the structure in this project was done by using software package STAAD-Pro which uses the limit state design methods that conform to the Indian Standard Code of Practice. The design is in confirmation with IS456-2000.

During their service life, some of the reinforced concrete structures often require modification and improvement in their performance through repair or rehabilitation. This mainly happens because of deterioration due to many contributing factors. The exposure to an aggressive environment causing corrosion, improper detailing, failure in the bonding between beam-column joints, a significant increase in service loads and improper design are some of the factors. Another important factor is from the unexpected external lateral loads such as wind or seismic forces acting on a structure, etc. These loads affect the structure leading to cracking, spalling, loss of strength, deflection, etc.

There are also quite a few existing structures which are observed to not be fulfilling the specified requirements mainly because of change or an upgrade in the design standards, significant increase in the loading, errors in design or detailing or even due to accident events like earthquakes.

In such circumstances, there can be two possible solutions:

A. Replacement
B. Retrofitting

Considering the high costs for material and labour, the environmental impact and the general inconvenience caused in case of replacement, it is often better to repair or upgrade the structure by retrofitting.

Retrofitting refers to assessing the existing condition of the structure and deciding which component needs to be repaired or restored for future requirement.

II. SPECIFICATIONS OF THE PROJECT

		S+G+4 upper floors	S+G+6 upper floors
Height of Building	=	18.72m	24.96m
Built Up Area	=	198.41m^2	198.41m^2
Number of Storeyes	=	S+G+4	S+G+6

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Floor Height	=	3.12m	3.12m
Type of Masonry	=	Aerocon AAC blocks	Porotherm Clay blocks (for 5^{th} and 6^{th} floor only)
Density of blocks	=	550-700 kg/m^3	1800 kg/m^3
Wall Thickness	=	150mm (for external members)	
	=	100mm (for internal members)	
Slab Thickness	=	150mm	

III. METHODOLOGY

A. Initial Autocad work which includes creating the grid lines to be used for modelling, referring to the plan given.
B. Modelling of building in STAAD-Pro for the existing design (S+G+4) and for the design when two additional floors are added (S+G+6).
C. Assigning the member properties and supports.
D. Calculation of loads for the existing S+G+4 model and for the model when two additional floors are added (S+G+6) for which the use of Porotherm clay blocks is proposed.
E. Applying the loads and load combinations on the respective floors of the structure.
F. Analysis of the structure.
G. Design of the structural elements such as beams, columns and footings of the existing model using IS code methods and calculation of their existing sizes or dimensions.
H. Check for the column and footing strength from analysis and identification of the members where retrofitting is required.
I. The check for the safety of the selected columns after the increase in their sizes (jacketing) done on a trial and error basis.
J. Column Grouping for both the models based on the vertical load values (FY) for footing.
K. For the case of S+G+4 model, the existing sizes of each group are calculated and tabulated.
L. For the case of S+G+6 model, the increased sizes of each group are calculated and tabulated. The change in the sizes are observed and noted.
M. Suggesting the suitable retrofitting techniques for the required columns and beams.

IV. MODELLING AND MEMBER PROPERTIES

A. Modelling

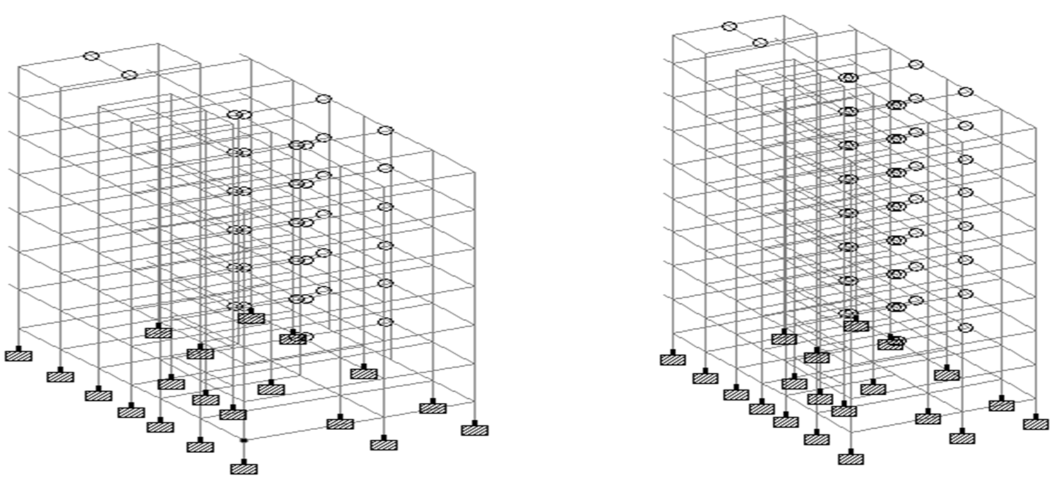

Fig. 1 3D Model in STAAD-Pro for **S+G+4** and **S+G+6**

B. Assigning the member properties

Specifications for:
Columns: 8”x24” – YD = 0.6m, ZD = 0.2m
Lift: 6”x24” – YD = 0.6m, ZD = 0.15m
Stairs: 8”x24” – YD = 0.6m, ZD = 0.2m
Beam: 8”x24” – YD = 0.6m, ZD = 0.2m

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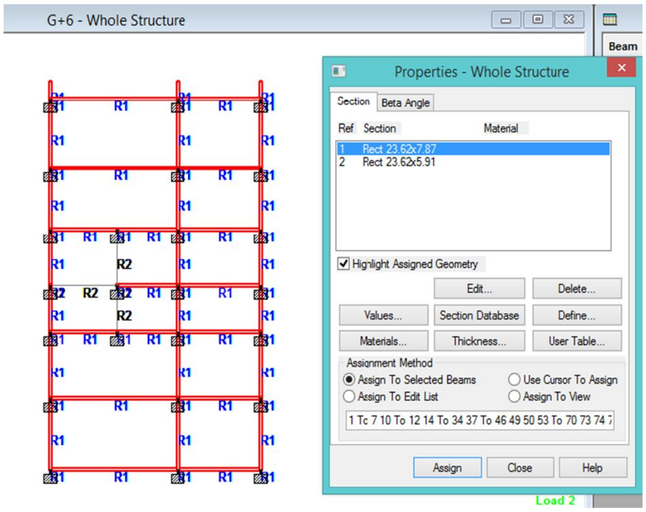

Fig. 2 Member Property – 200mm*600mm

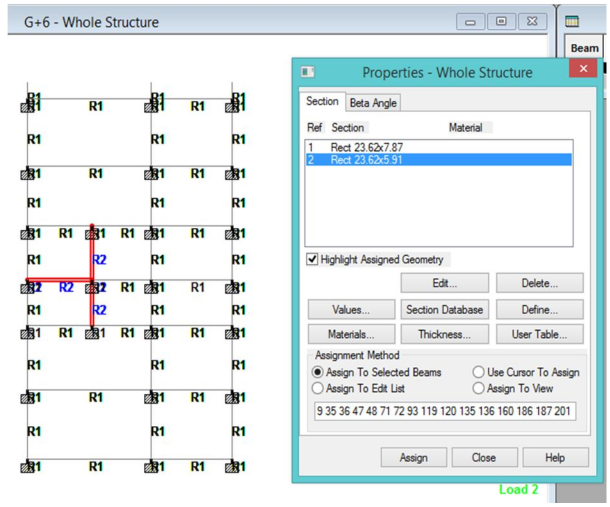

Fig. 3 Member Property – 150mm*600mm

V. LOAD CALCULATION

A. Dead load

As mentioned earlier, the walls of the stilt floor, ground floor and the next four floors are proposed to be of Aerocon AAC blocks. However, the walls of the added two floors are proposed to be of the Porotherm Clay blocks.

B. Wall Load

Width of wall to be assigned for:

External members = 6" = 0.15m

Internal/Partition members = 4" = 0.1m

Floor height = 3.12m

Height of wall = floor height – depth of beam = 3.12 – 0.6 = 2.52m

Aerocon AAC blocks density = 650 kg/m^3

= (650*9.81)/1000

= 6.37 kN/m^3

∴ Wall load from Aerocon AAC blocks to be assigned to external members

= width of wall x height of wall x block density

= 0.15 x 2.52 x 6.37 = 2.4 kN/m

∴ Wall load from Aerocon AAC blocks to be assigned to internal members

= 0.1 x 2.52 x 6.37 = 1.6 kN/m

Only for the case of S+G+6 model –

Porotherm Clay blocks density = 1800 kg/m^3 = (1800*9.81)/1000

= 17.65 kN/m^3

Wall load from Porotherm Clay blocks to be assigned to external members

= width of wall x height of wall x block density

= 0.15 x 2.52 x 17.65 = 6.67 kN/m

Wall load from Portherm Clay blocks to be assigned to internal members

= 0.1 x 2.52 x 17.65 = 4.45 kN/m

Parapet Wall

Width = 4" = 0.1m, height = 0.75m

Wall load from Parapet wall = width x height x density = 0.1m x 0.75m x 20 kN/m^3

= 1.5 kN/m

C. DL from Slab

Thickness of slab = 150mm = 0.15m

∴ DL_{slab} = thickness x density of concrete = 0.15m x 25 kN/m^3
= 3.75 kN/m^2 + FF (2 kN/m^2)
= **5.75 kN/m^2**

which will be assigned as floor load in STAAD-Pro with the following specifications:

- Y_{min} = 3.12m, Y_{max} = 24.96m
  X_{min} = 0m, X_{max} = 10.86m
  Z_{min} = 0m, Z_{max} = 18.27m

Slab load from the cantilever portion (balcony):
DL = 3.75kN/m^2 x 0.85m (width of the cantilever portion)
= 3.18 kN/m, which is assigned as a UDL on the supporting beam.

D. Live Load –

The imposed/live load values from IS 875- Part 2 are as follows:
From table 1, page 7 – Imposed load for rooms = 2 kN/m^2
Imposed load for toilets/bathrooms = 2 kN/m^2
From table 2, page 14 – Imposed load for roofs = 1.75 kN/m^2; however for safer side we can input this value as 2 kN/m^2 for the building.
which will be assigned as floor load in STAAD-Pro with the following specifications:
Y_{min} = 3.12m, Y_{max} = 24.96m
X_{min} = 0m, X_{max} = 10.86m
Z_{min} = 0m, Z_{max} = 18.27m
Imposed load from the cantilever portion (balcony)
Imposed load for balconies = 3kN/m^2, which will be assigned to the supporting beam as UDL by multiplying this value with the width of the cantilever portion (balcony) as given below:
Imposed Load from balconies = 3kN/m^2 x 0.85m = 2.55 kN/m.

E. Staircase Load

Rise= 0.15 m
Thread= 0.280 m
Waist slab thickness=0.15 m
Self-weight of waist slab= 0.15m x 25kN/m^3 = 3.75 kN/m^2
Step weight= 0.5 x 3.75 = 1.875kN/m^2
FL = 2 kN/m^2
LL = 3 kN/m^2
Total load = 3.75+1.875+2+ 3 = 10.625kN/m^2
For horizontal, Total load is 10.625/cos28.1 = 12.04 kN/m^2

∴ Intensity of loads R1 = R2= 3.9*12.04/2 = 23.48 kN/m applied on Staircase beams.

F. Water Tank Load

Capacity of water tank = 135 lpcd x 16 (people on each floor) x 7 (floors)
= 15000 litres
We will be including 2 tanks with each tank capacity = 7500 litres
Capacity (in m^3) = 7.5 m^3
Height of tank = 1.5m
Area x 1.5 = 7.5
(πx d^2/4) = 5m^2
∴ Diameter d = 2.5m

G. Lift Load

It is applied as nodal load on columns and for this building, a maximum of 10 persons' weight is considered and weight of 1 person is assumed as 100 kg.
Weight of 10 persons = 10x100 = 1000 kg

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Moving Car weight = 1000 kg
Counter Weight = 2000 kg
Total load = 1000+1000+2000 = 4000 kg
Load on each column = 4000/4 = 1000 kg or 10 kN
Considering allowance factor = 10
Total load on each column = 10x10 = 100 kN

H. Diagrams

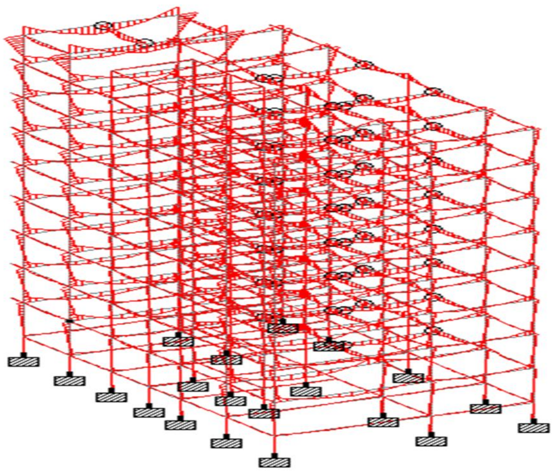

Fig. 4 Bending Moment Diagram 3D model

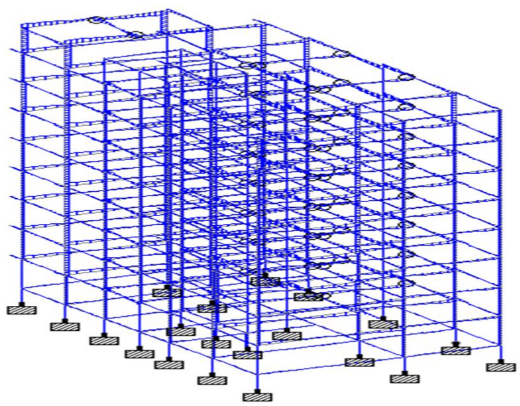

Fig. 5 Shear Force Diagram 3D model

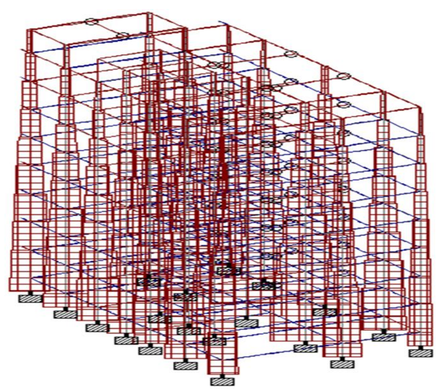

Fig. 6 Axial Force Diagram 3D model

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VI. RETROFITTING

A. Retrofitting of columns

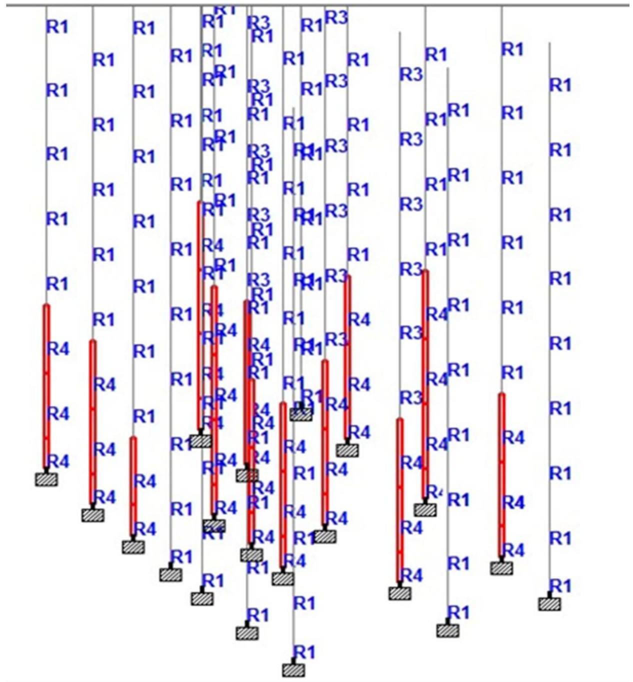

Fig. 7 Identification of the required Columns for Retrofitting from Staad-Pro

TABLE INCREASE IN THE SIZES OF THE REQUIRED COLUMNS

Column Number	Existing Column Sizes from S+G+4 (mm)	Increase in Column Sizes from S+G+6 (mm)	Number of Floors for Retrofitting
37	600*200	700*230	G+1
38	600*200	700*230	G+3
39	600*200	-	Safe
40	600*200	700*230	G+1
41	650*230	700*230	G+2
42	600*200	700*230	G+2
43	600*200	700*230	G
44	600*200	700*230	G+3
47	600*200	-	Safe
48	600*200	700*230	G+2
49	650*230	700*230	G+2
50	600*200	700*230	G+3
51	600*200	-	Safe
52	600*200	700*230	G+1
55	600*200	-	Safe
56	650*230	700*230	G+2
57	600*200	700*230	G+1
58	600*200	-	Safe
59	600*200	-	Safe
60	600*200	-	Safe

For this case, most common method or technique applied for retrofitting in columns is by concrete jacketing. Retrofitting in columns is also done by steel plate jacketing which is mainly adopted when increasing the sizes of columns is not preferred. These methods are as shown in the figures 8 and 9 below.

Fig. 8 Retrofitting in Columns by Concrete Jacketing

Fig. 9 Retrofitting in Columns by Steel Plate Jacketing

B. Retrofitting for footing

1) Footing Design

Bearing Capacity of soil, SBC = 150 kN/m^2.
Characteristic Strength of Concrete, f_{ck} = 20 N/mm^2.
Yield Strength of Steel, f_y = 415 N/mm^2.

For the case of S+G+4 storeys model, we observe that the total pressure on the footing is lesser than the safe bearing capacity of the soil. Therefore, the footing size provided is sufficient to take loads. However, this is not true in the case of S+G+6 storeys model and thus, a considerable increase in the size of footing is required.

The first step includes the grouping of columns for both the models based on the reaction (FY) values from the Postprocessing tab in STAAD-PRO, as shown below.

TABLE II COLUMN GROUPING FOR S+G+4

Group	Node	Fy
C1	192	363.685
C2	171	457.366
C2	190	509.827
C3	183	586.081
C3	179	648.912
C4	191	665.448

C4	175	698.155
C5	187	729.144
C5	169	734.302
C6	189	784.225
C6	172	808.184
C6	184	826.563
C7	174	829.764
C7	180	875.449
C8	170	911.773
C8	176	951.552
C9	182	1017.33
C10	188	1353.774
C10	181	1433.412
C11	173	1470.731

TABLE III COLUMN GROUPING FOR S+G+6

Group	Node	Fy
C1	48	581.929
C2	27	719.072
C2	46	736.108
C3	39	817.04
C3	35	879.086
C4	47	929.666
C4	31	973.028
C5	43	984.083
C5	25	995.373
C6	40	1081.051
C6	28	1082.904
C6	45	1092.332
C7	30	1136.5
C7	36	1206.533
C8	26	1219.419
C8	32	1251.5
C9	38	1303.059
C10	44	1776.611
C10	37	1795.103
C11	29	1892.248

The existing size and the required increase in size (after retrofitting) of each column grouping can hence be determined from the footing design for both the cases. Footing design for group C1 is shown below.

Design for S+G+4

Group : C1 Node in STAAD-PRO : 192

P = 363.685 kN

ΔP (self weight of footing) = 10% of P = 36.3685 kN

$\therefore$ Total load = P + ΔP= 400.05 kN

Area of footing, **A** = $\frac{P+\Delta P}{SBC} = \frac{400.05}{150}$ = 2.68 m^2

$\therefore$ (0.6+2x) (0.2+2x) = 2.68 m^2

$4x^2 + 1.6x - 2.56 = 0$

$\therefore$ x =0.625 m

Using this value of x, we can determine the Length and width of the footing.

Hence, the initial size of the footing:
Length, L = 0.6 + (2 x 0.625) = **1.85 m**.
Width, L = 0.2 + (2 x 0.625) = **1.45 m**.

C. Design for S+G+6

Group : C1 Node in STAAD-PRO : 48
P = 581.929 kN
ΔP (self weight of footing) = 10% of P = 58.1929 kN
∴ Total load = P + ΔP= 640.122kN
Area of footing, **A =** $\frac{P+\Delta P}{SBC}$
$= \frac{640.122}{150} = 4.27$ m^2
∴ (0.6+2x) (0.2+2x) = 4.27 m^2

$4x^2 + 1.6x - 4.15 = 0$
∴ x =0.88 m

Using this value of x, we can determine the Length and width of the footing.
Hence, the increased size of the footing:
Length, L = 0.6 + (2 x 0.838) = 2.3 m.
Width, L = 0.2 + (2 x 0.838) = 1.9 m. Similar calculations are done for the remaining groups and the results for the existing size of footing and the increased size of footing (after retrofitting) are shown in the table below:

TABLE IV EXISTING AND REQUIRED FOOTING SIZES

S+G+4			S+G+6	
GROUP	FOOTING DIMENSIONS (EXISTING)		FOOTING DIMENSIONS (REQUIRED)	
	LENGTH (M)	WIDTH (M)	LENGTH (M)	WIDTH (M)
C1	1.85	1.45	2.35	1.95
C2	2.14	1.74	2.64	2.24
C3	2.39	2	2.89	2.5
C4	2.47	2.07	2.97	2.57
C5	2.53	2.13	3.03	2.63
C6	2.67	2.27	3.17	2.77
C7	2.74	2.34	3.24	2.84
C8	2.85	2.45	3.35	2.95
C9	2.94	2.54	3.64	3.24
C10	3.45	3.03	3.95	3.53
C11	3.5	3.08	4	3.58

VII. CONCLUSION

A. The existing sizes of the columns and footing were not capable of taking the additional loads due to the additional storeys in the second model. This is because with the increased loads on the structure, the members turn out to be insufficient in terms of their load carrying capacity.
B. The retrofitting design for both column and footing is required after the addition of two storeys on top of the existing S+G+4 building.
C. Retrofitting increases the load carrying capacity of the members by strengthening of the structure and enhances its performance.

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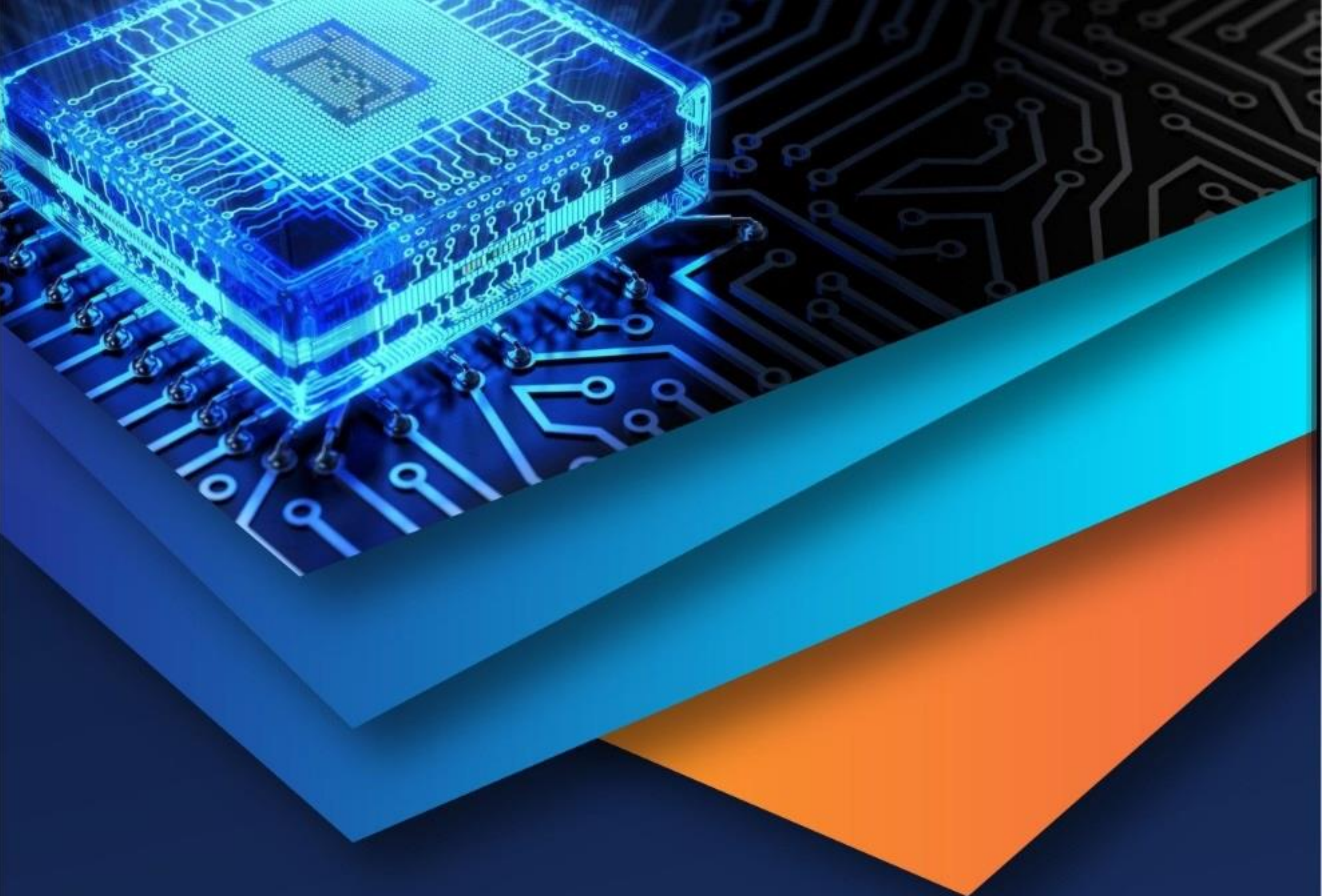

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